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ENGINEERING NOTE	**FE3130**	**M8047**	**1 of 6**

Author	Department	Date
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Program - Project - Job: SNS-FE Ion Source/LEBT
Ion Source and LEBT Mechanical Systems

Title: **SNS-Front End Systems Vacuum Systems**

1. SCOPE

This report covers the vacuum design and equipment for the SNS Front-End Systems ion source and Low Energy Beam Transport (LEBT) chamber. The components covered here are the chamber, vacuum pumps, vacuum gauges, and the design of the main insulator. The fabrication of the main insulator is covered in a separate note.

2. BACKGROUND

The ion source and Low Energy Beam Transport of the SNS Front End systems is designed to produce and transport a 65 mA H- beam at a 6% duty factor and 75 keV energy into the Radio Frequency Quadrupole (RFQ) for further acceleration. The ion source plasma generator is floated at a potential of 65 kV with respect to the vacuum chamber, which is at ground potential, by what is termed the Main Insulator. The extracted H- beam is accelerated through the five LEBT electrodes, which shape and steer the beam prior to transferring it into the RFQ.

3. REQUIREMENTS

3.1 For the ion source plasma generator to generate enough current, the H_2 gas flow has been determined to be optimal at 20-30 sccm (.25-.38 Torr•l/sec).
3.2 To maintain the charge exchange losses below 10% of the extracted beam current, the vacuum is required to remain below 1.0×10^{-4} Torr during operating conditions.
3.3 The main insulator must stand off a -65 kV potential across its surface.
3.4 The main insulator must also resist a 15 psi vacuum load because it is also the main support from which both the reentrant cylinder and ion source are mounted.
3.5 In this regime of high voltage and high vacuum, triple-point protections must be employed as well in the design of the main insulating structures.

4. DESIGN PHILOSOPHY

The length of the LEBT electrode structure is only a little more than 10 cm long. A standard "stacked" insulation column with varying lengths of ceramic tubes separated by corona rings would have been impractical in this case, not to mention expensive. The form of the electrodes would not have been conducive for adequate vacuum pumping either, so a novel approach was explored.

The vacuum chamber design was designed as a flat, cylindrical stainless steel chamber about 9" long and 27" in diameter. A total of six main ports—three pump ports, and three feedthru ports—extended radially from the chamber. See Figure 1. This design also allows the ion source to tilt as necessary, and allows it to be accessible for easy maintenance.

The electrical insulation for the plasma generator's -65kV operation was designed as a cast epoxy flange that has a cross-section similar to the letter "S". It was designed with a brass screen that was cast in place, which helps define the electrical field through the insulator, preventing any abnormally high field gradients caused by “triple-points” (conductor-insulator-vacuum interfaces) at its edges. The reentrant cylinder, upon which the LEBT and ion source is mounted, is attached to this main insulator. See Figure 2.

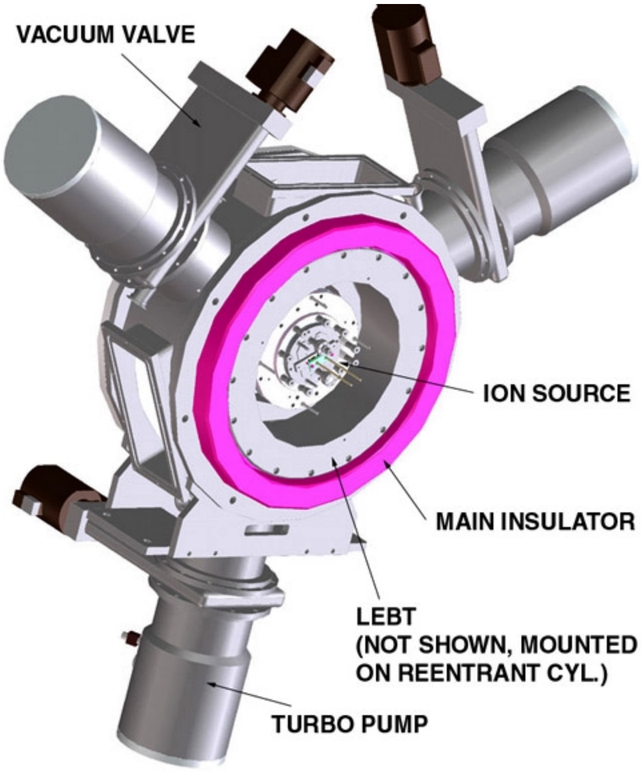

Figure 1. Picture of LEBT vacuum chamber (LEBT, feedthrus, and gauges not shown).

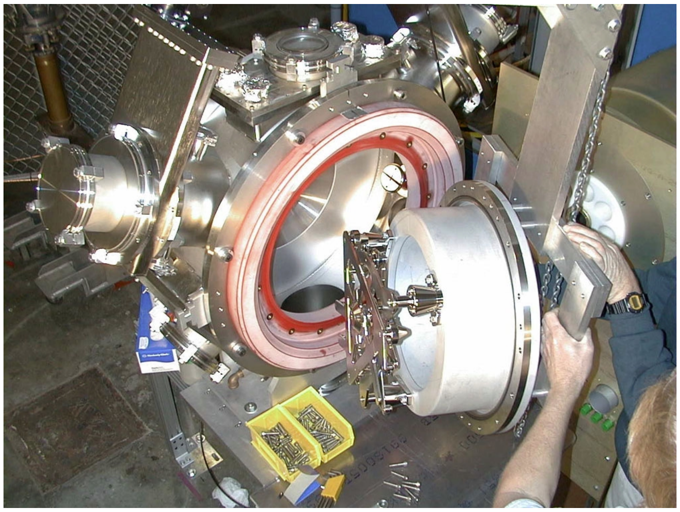

Figure 2. LEBT mounted on reentrant cylinder, prior to installation (ion source not shown).

5. DESIGN ANALYSES

5.1 For the vacuum requirements, the quick and dirty equation, $Q=PS$ (Q=throughput; P=ideal pressure; S=pump speed) gives us how much pumping is required. For the 30 sccm and 1.0×10^{-4} Torr case, we obtained a required pump speed of ~2500 l/sec required for this systsem. This value does not take into account geometry issues, constricted flows, or outgassing from the chamber walls.

5.2 A simple analysis was conducted for the wall thickness of the stainless steel chamber. Using the chart from LBNL Design Data 99 (Reinath, MacLaughlin, 7/70), the minimum wall thickness for a stainless steel vacuum vessel that is ~9" long by ~27" was extrapolated to about .081". The material chosen was .25" stainless sheet, which provides for a safety factor of more than 3.

5.3 For the reentrant cylinder and main insulator structural analyses, a Finite-Element Analysis (FEA) was conducted using the Mechanica (now a part of the Pro/E package). The geometry was input into a Mechanica mesh to determine the resultant stresses and deflections. The epoxy main insulator was calculated as experiencing a maximum of ~800 psi in compression, which is well below it's published compressive strength of 22,000 psi (See appendix A for manufacturer info.). The aluminum reentrant cylinder experienced close to 1200 psi, which is only 3% of its 45,000 psi tensile strength (for 6061-T6). See Appendix B for FEA plots.

5.4 The electrical analysis for the main insulator consisted of two parts: calculating the surface length of the insulator (an insulator's surface breaks down well before the insulator's bulk limit is reached), and calculating field gradients of the overall geometry. Table 1 shows the criteria used in this design. The surface of the insulator must stand off -65kV on the side exposed to the air, so the criteria of 8 kV/cm was applied. Given that the surface length on the air side of the insulator is about 5.75", a safety factor of 1.8 was obtained. The vacuum side has a surface length of about 6.5", which has a safety factor of 3.8.

5.5 ANSYS FEA software was then used to determine the electrical field and gradients of the main insulator geometry. Next, the geometry was entered into ANSYS to determine its electrical properties through the bulk, and to determine the effect of the brass screen. The maximum voltage gradient seen in the bulk of the insulator is around 90 kV/cm, which is acceptable within the material's ~55 kV/mm rating (See Appendix A). A local maximum of about 25 kV/cm in the air gap at the radius of the reentrant flange was seen, but the average over the entire gap was ~18 kV/cm. Although this value is higher than the 10 kV/cm value specified in Table 1, the judgment was that the analysis was overestimating the gradient, and a full test would be conducted on the geometry. Section 8, "Electrical Performance," describes the test results. See Appendix C for FEA plots.

Type	Vacuum	Air
Gap*:	$d = .01414V^{3/2}/10$	10 kV/cm
Insulator Surface:	15 kV/cm	8 kV/cm

Table 1. Voltage criteria for Insulator design.
*** Units of *d*: cm; *V*: kV.**

6. VACUUM EQUIPMENT

The vacuum equipment used is shown in Table 2.

Equipment	**Description**	**Manufacturer**	**Part Number**
Turbo Pump*	1000 l/sec turbo, magnetic bearings, turbo molecular drag stage (~725 l/sec H_2 pumping)	Pfieffer	TMH 1000
Backing Pump*	Diaphragm pump	Varian	MD 60
Vacuum Valve*	8" (ISO NW200) flange	MDC	P/N 307007
In-line Valve*	1-1/2" KF	MDC	P/N 321054
Low-Profile gate valve	Separates LEBT vacuum from RFQ vacuum	LBNL-built	LBNL Eng. Note M7770 (Pruyn, Virostek)
Bourdon Tube	Analog pressure and vacuum gauge, NW40 flange	MDC	P/N 432012
Gauge	Mini-Convectron, measures atm pressure	Granville-Phillips	P/N 275913-EU
Gauge	Micro Ion Gauge, measures from $5e^{-2}$ to $1e^{-9}$ Torr	Granville-Phillips	P/N 354002-yk-t Micrion Module
Pressure Transducer		Leighton Stone	RV34A21 w/ PB20A Switch
Check valve	Overpressure check valve, 1/3 psi	Swagelok	SS-CHF8-1/3

Table 2. Vacuum equipment required for the system.
*** Denotes that a quantity of 3 ea. is required for entire system.**

7. VACUUM PERFORMANCE

7.1 After fabrication, the vacuum performance of the system has been shown to meet specifications. Initial tests of the chamber under vacuum showed a base of pressure of around 5×10^{-6} Torr. This relatively high pressure was expected, due to the unconditioned surfaces of the chamber walls, and especially the epoxy insulator. Over the period of a week, the pressure dropped closer to 1×10^{-6} Torr. Over the period of the subsequent month and beyond, the base pressure remained in the low 10^{-7} Torr.

7.2 During operation, however, is where the vacuum performance really matters. Figure 3 shows a chart of the vacuum pressure as a function of gas flow. The gas flow regime in which the system will be run is optimized at near 25 sccm. According to the figure, the pressure remains below 5×10^{-5} Torr during operation, which keeps charge exchange losses to the beam at a minimum.

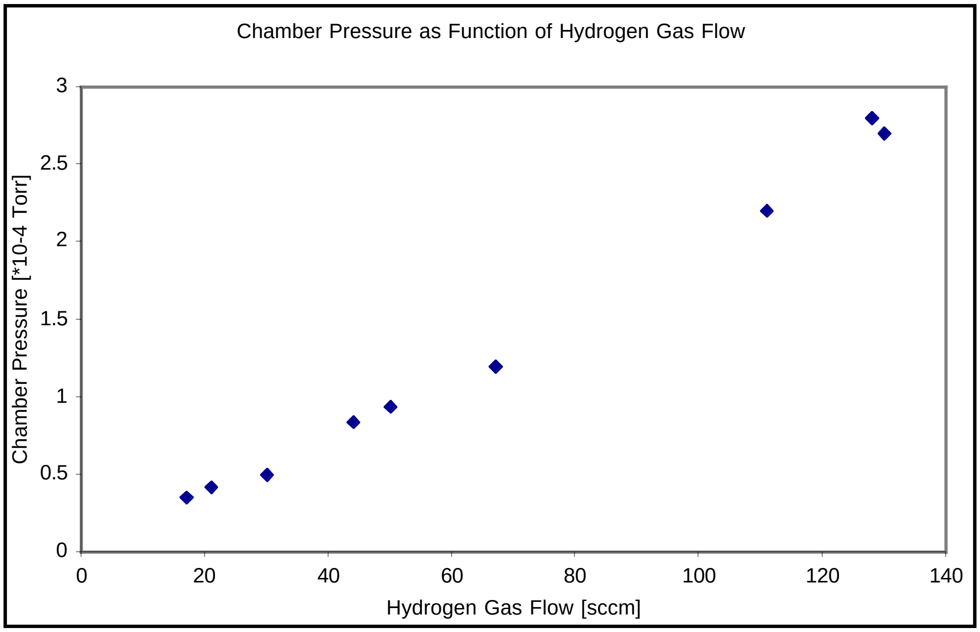

Figure 3. Chamber pressure as a function of hydrogen gas flow. All three turbo pumps were operating for these measurements.

8. ELECTRICAL PERFORMANCE

The main insulator was hi-potted after about two weeks of conditioning under vacuum using a portable 150 kV power supply. The highest voltage reached was close to 75 kV, and was held for approximately 5 minutes prior to ramping the potential back down. It was noted that some corona was heard, but no arcing took place. Since the specifications call for only a 65 kV maximum potential, it was considered that there is at least a 15% safety margin in the design of the insulator.

9. ADDITIONAL REFERENCE DOCUMENTS

Fabrication of the 65kV Insulator: Eng. Note M8048 by Dan Cheng
SNS Prototype LEBT FDR 3/22/99, FE-ME-033 by Dan Cheng
LEBT-RFQ Isolation Valve: Eng. Note M7770 by John Pruyn
Initial Hi-Pot Testing of the Ion Source/LEBT Design, FE-EE-009 by Don Williams

10. KEY SNS-FE DESIGN PERSONNEL

Dan Cheng: Primary Engineer
Sam Mukherjee: Mechanical Engineer
John Pruyn: Primary Designer
Rainer Thomae: Scientist/Operator
Don Williams
Tom McVeigh

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11. DESIGN DRAWINGS

- Vacuum Chamber
  - 25B0696A Initial Vacuum Chamber Fabrication
  - 25B0786A Vacuum Chamber, 2 pages
  - 25B0776A Rect. Flange
- Main Insulator Flange:
  - 21G8964A LEBT insulator Flange Assembly
  - 21G8994 Reentrant Spacer Flange
- Flanges:
  - 25B0726A Bulkhead Flange
  - 21G8986A Temp Last LEBT Electrode
  - 21G7514 Viewport/Gauge Weldment
  - 21G7504 Viewport/Gauge flange machining
  - 21G8104 Viewport/Feedthru Flange weldment
  - 21G8084 Viewport/Feedthru Flange machining
  - 21G8114 Modified NW160 Blank Flange
  - 21G8094 Feedthru Flange Machining
  - 21G7754 LEBT Viewport HV Feedthru Flange
- Support Flanges:
  - 25B0876 Stand Face - Vacuum Chamber
  - 25B0886 Stand Foot - Vacuum Chamber

Appendix A

Epoxy Insulator Manufacturer Info

HYSOL DIVISION
THE DEXTER CORPORATION

ELECTRICAL
INSULATING
MATERIALS

BULLETIN E3-342E

HYSOL®

SHOCK RESISTANT, LOW EXOTHERM CASTING SYSTEMS
C9-4183 & HD3485 - Filled C9-4186 & HD3485 - Highly Filled

Our Resin

1.0 DESCRIPTION

HYSOL casting compounds C9-4183 or C9-4186, when used with HYSOL hardener HD3485, are low exotherm, long pot life casting systems. These systems show good shock resistance where low temperature operation is required. They are being widely used for massive castings . . . up to 400 pounds . . . where high electrical insulation properties must be maintained.

1.1 Colored versions exhibiting identical properties to C9-4183 are available as follows: C9-4188 yellow, C9-4190 red, C9-4198 green, C9-4207 blue, C9-4215 black.

2.0 SPECIFICATION OF PRODUCT

	C9-4183*	C9-4186*	HD3485	Test Method
Color			Gardner 4	ASTM D 1544
Color	Tan	Tan		Visual
Amine equivalent (meq $HClO_4$/gm)			7.6-8.6	HYSOL 14 A
Epoxy equivalent weight	335-440	500-618		ASTM D 1652
Filler content, %	48-52	63-67		ASTM D 2584
Specific gravity @ 25°C (77°F)	1.50-1.65	1.75-1.90	1.10-1.20	ASTM D 1475
Viscosity @ 25°C (77°F)				ASTM D 2393
Brookfield RVF				
Spindle 6, Speed 4, cps	70,000-100,000			
Spindle 7, Speed 20, cps		100,000-200,000		
Spindle 3, Speed 10, cps			3,000-4,500	
Shelf life @ 25°C (77°F), months (minimum from date of shipment)	6	12	12	

NOTE: The resin base of these compounds meets the requirements of ASTM D 1763, specification for epoxy resins.

3.0 TYPICAL CURED CHARACTERISTICS — Values are not intended for use in preparation of specifications. All measurements taken at 25°C (77°F) unless otherwise noted.

FROM
K.R. ANDERSON
727-2800

3.1 PHYSICAL

	C9-4183/HD3485	C9-4186/HD3485	Test Method
Color	Tan	Tan	Visual
Coefficient of linear thermal expansion, in/in/°C (30°C to 90°C)	78×10^{-6}	68×10^{-6}	ASTM D 1674
Compressive strength, psi	22,000	22,000	ASTM D 695
Density, lb/cu in	0.057	0.063	ASTM D 792
Elongation, %	1.00	1.08	ASTM D 638
Filler content, %	47	62	ASTM D 2584
Flexural strength, psi	17,000	17,000	ASTM D 790
Hardness, Shore D	85	87	ASTM D 2240
Heat deflection temperature @ 264 psi, °C (°F)	80 (176)	80 (176)	ASTM D 648
Izod impact strength, ft-lb/in. of notch	0.23	0.24	ASTM D 256
Linear shrinkage, %	0.4-0.6	0.3-0.4	ASTM D 2566
Moisture absorption (24 hour immersion), %	0.24	0.22	ASTM D 570
Specific gravity	1.53	1.77	ASTM D 792
Tensile strength, psi	6,400	7,000	ASTM D 638
Thermal conductivity, cal x cm/(sec x sq cm x °C)	12×10^{-4}	16×10^{-4}	ASTM D 1674

3.2 CURED ELECTRICAL CHARACTERISTICS

	C9-4183/HD3485	C9-4186/HD3485	
Dielectric strength @ 10 mil thickness, volts/mil	1400	1350	ASTM D 149
Arc resistance, seconds	138	163	ASTM D 495
Guide to operating class, IEEE	130	130	

	C9-4183/HD3485				C9-4186/HD3485			
	25°C		105°C		25°C		105°C	
	K	D	K	D	K	D	K	D
100 Hz	4.4	0.007	6.4	0.324	4.4	0.007	6.4	0.351
100 kHz	4.2	0.012	4.8	0.021	4.3	0.013	4.9	0.024
Vol res	7×10^{13}		1×10^{11}		6×10^{13}		2×10^{10}	

K = Dielectric constant by ASTM D 150
D = Dissipation factor by ASTM D 150
Vol res = Volume resistivity in ohm-cm by ASTM D 257

4.0 HANDLING

		C9-4183/HD3485	C9-4186/HD3486
4.1	Mix ratio, parts by weight*	100/7	100/5
	Mix ratio, parts by volume*	100/9	100/7.5
	Pot life @ 25°C (77°F) (200 gram mass), hours	24	24
	@75°C (167°F) (200 gram mass), hours	3	3
	Viscosity @ 75°C (167°F), cps		
	Spindle 1, Speed 10	500	
	Spindle 4, Speed 20		7,000
	Peak exothermic temperature (200 gram mass) °C (°F)	None	None
	Gel time @ 75°C (167°F), hours	5	5

\+ To insure complete compatibility of resin and hardener, mix quantities of up to one gallon at approximately 100°C (212°F) and larger quantities at 50-60°C (122-140°F).

*Mix ratio of these materials is fixed by their chemistry. Any attempt to increase or decrease the cure rate by adding more or less hardener will result in degraded materials.

4.2 Mixing Instructions

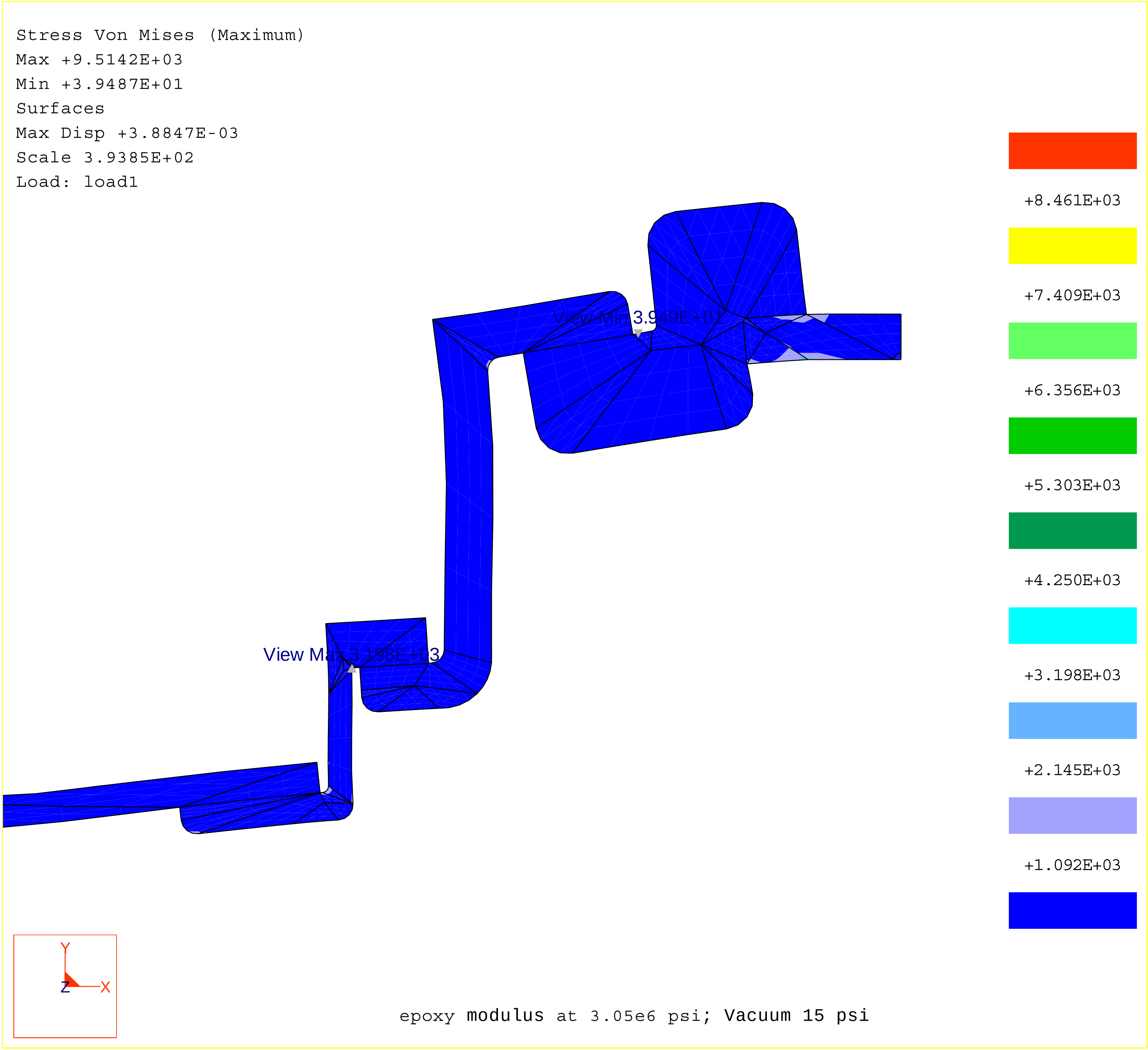
Heat base to 50°C to 75°C (122°F to 167°F), add hardener, mix, deair and cast into preheated 75°C (167°F) mold. In small masses, it may be necessary to bring the temperature of the mixture to 85°C (185°F) to get complete compatibility of base of hardener.

Filled resins may tend to settle during storage. Thorough mixing is required each time they are used.

Appendix B

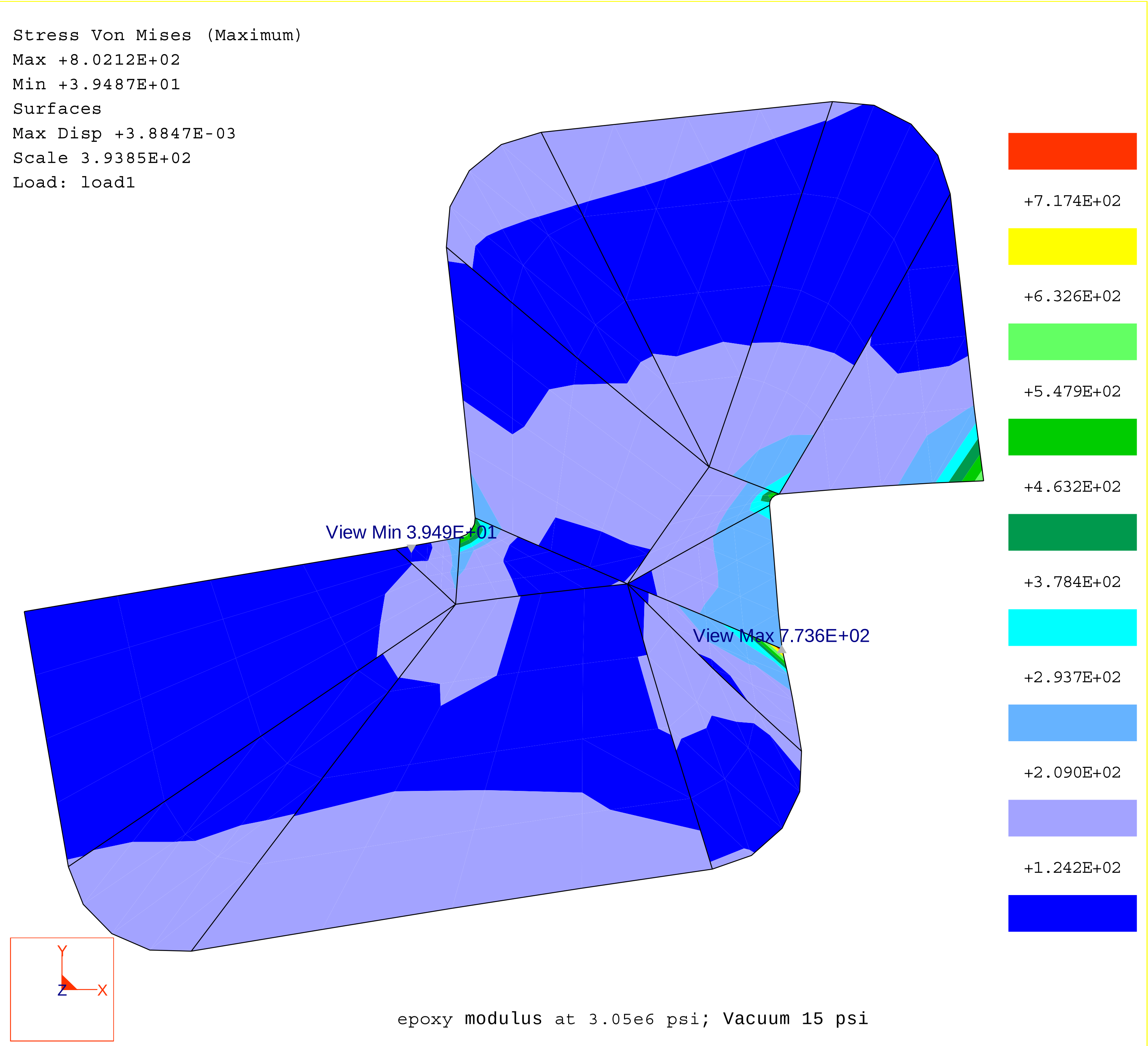
Insulator and Reentrant Cylinder FEA Structural Analyses

Plot 1. Combined structure results (Von Mises Stress, units in psi)
Plot 2. Epoxy Insulator-only structural results (Von Mises, units in psi)
Plot 3. Structural “Y” (axial) displacement plot (units in inches)
Plot 4. Structural “X” (radial) displacement plot (units in inches)

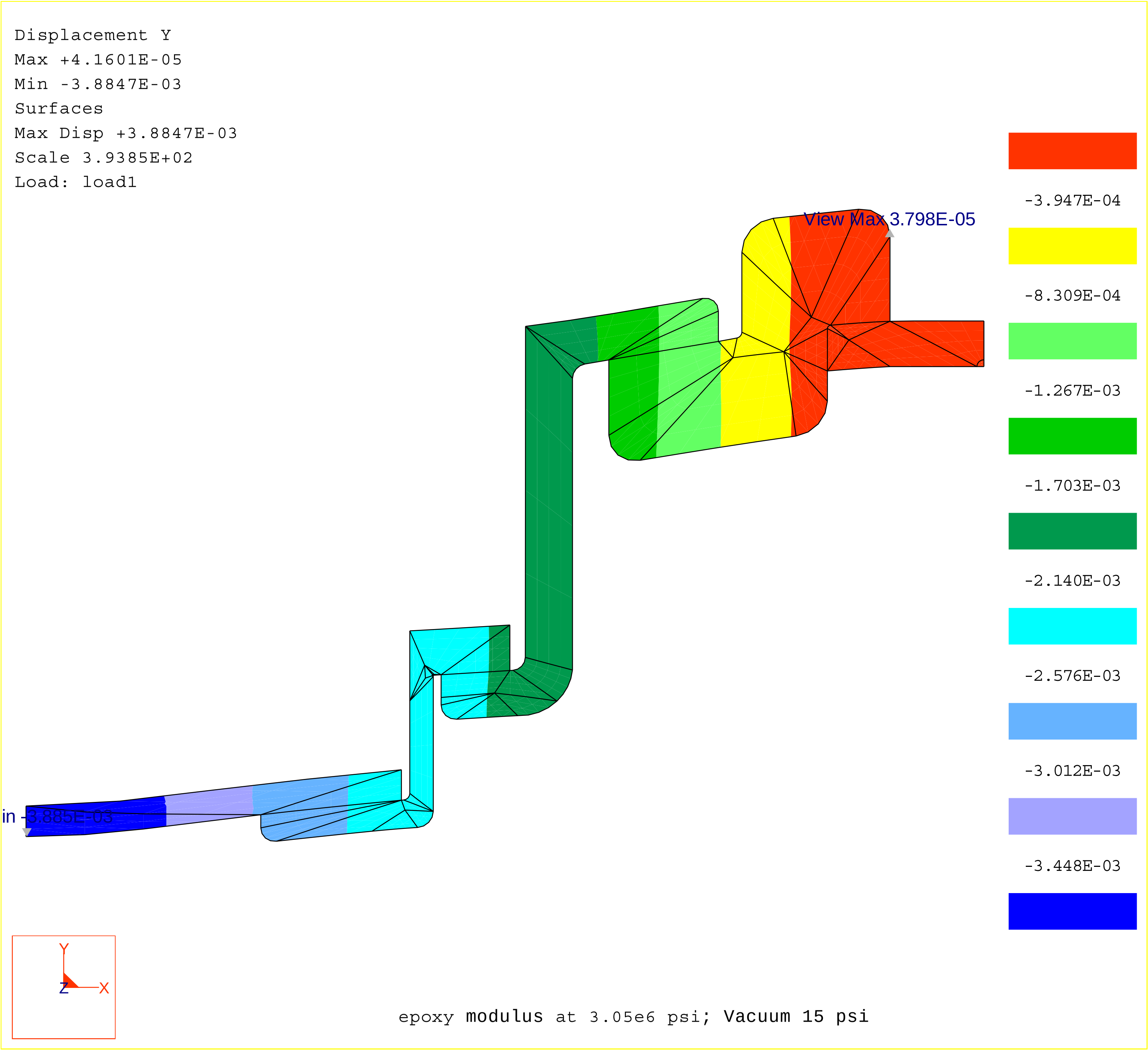


Stress Von Mises (Maximum)
Max +9.5142E+03
Min +3.9487E+01
Surfaces
Max Disp +3.8847E-03
Scale 3.9385E+02
Load: load1

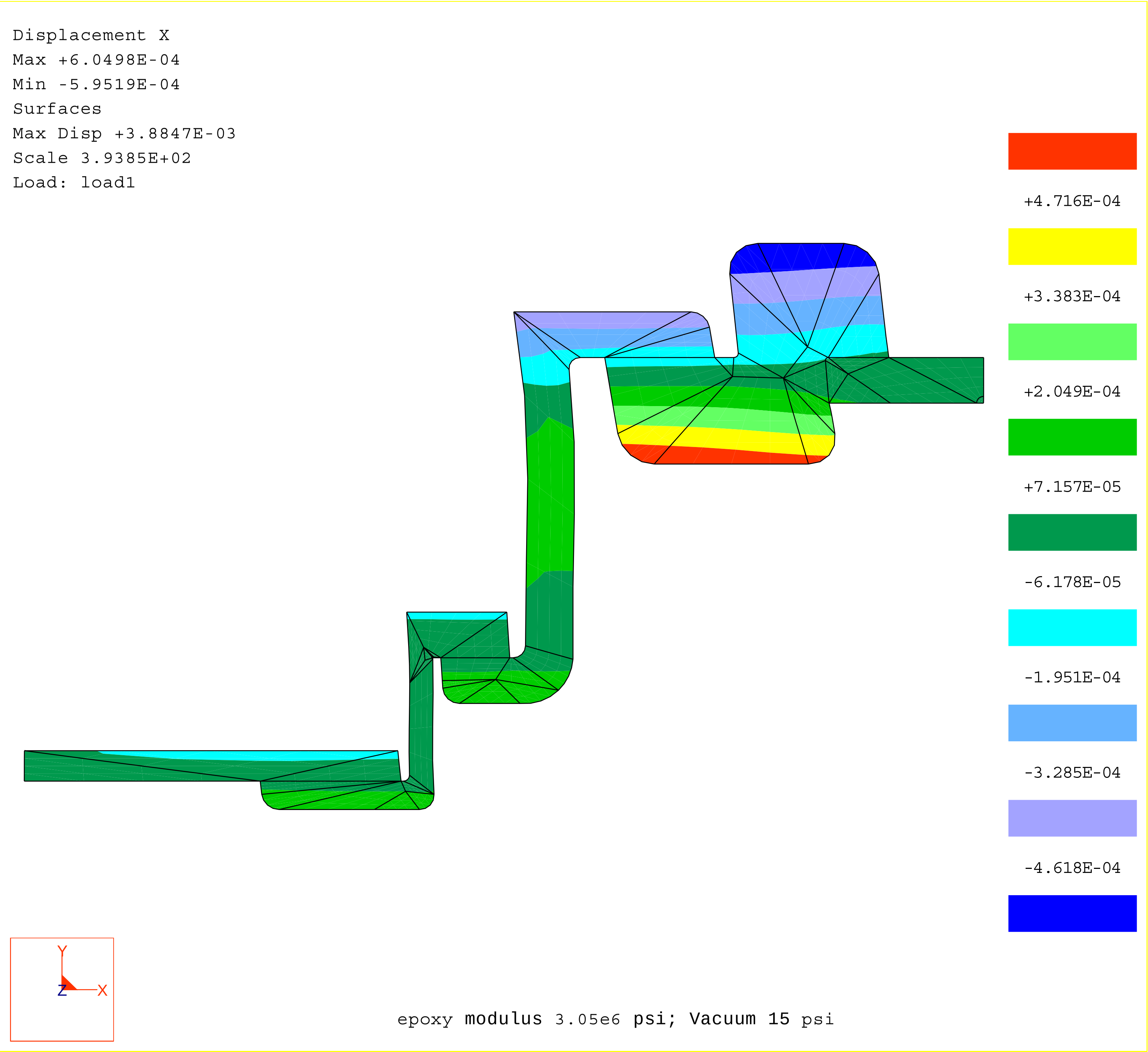
epoxy modulus at 3.05e6 psi; Vacuum 15 psi



epoxy modulus at 3.05e6 psi; Vacuum 15 psi



epoxy modulus at 3.05e6 psi; Vacuum 15 psi

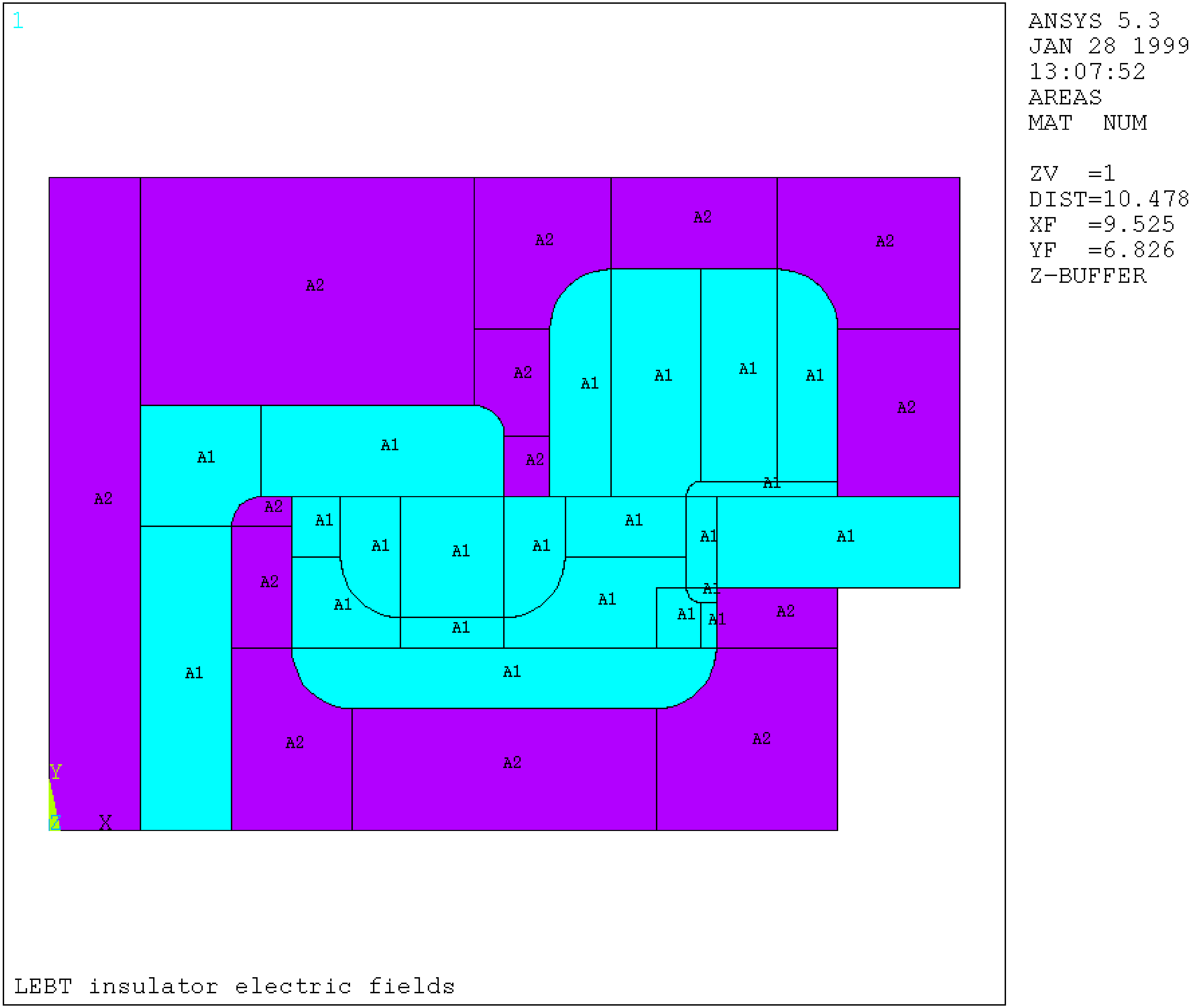


epoxy modulus 3.05e6 psi; Vacuum 15 psi

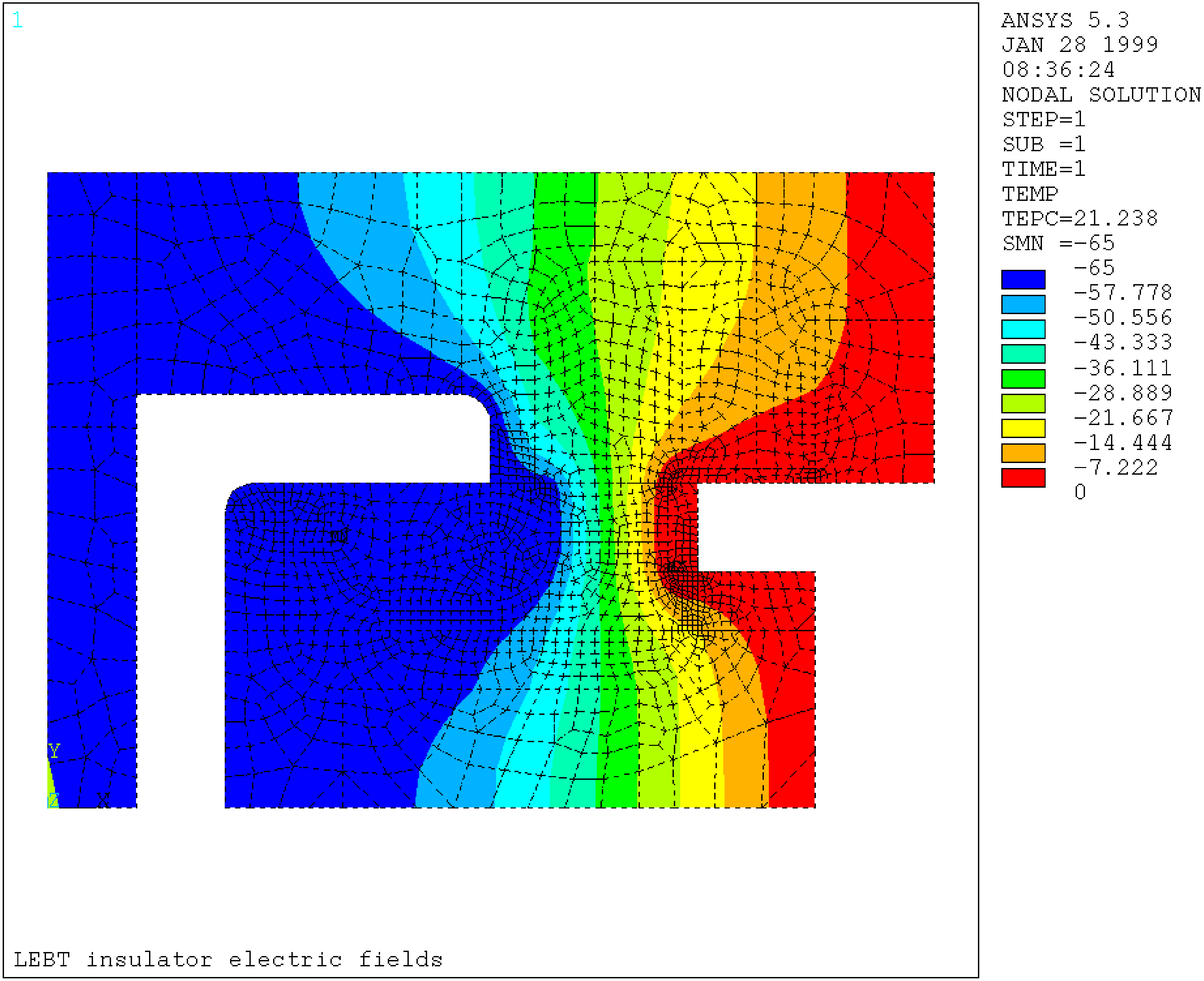
Appendix C

Epoxy Insulator FEA Electrical Analyses

Plot 1. Model view of cross section (cyan: insulator & flanges; purple: air)
Plot 2. Electrical Field Plot (units in kV)
Plot 3. Electrical Filed Plot Through Insulator only (units in kV)
Plot 4. Electrical Field Gradient Plot (units in kV/cm)
Plot 5. Electrical Field Gradient Plot, Blowup (unit in kV/cm)



LEBT insulator electric fields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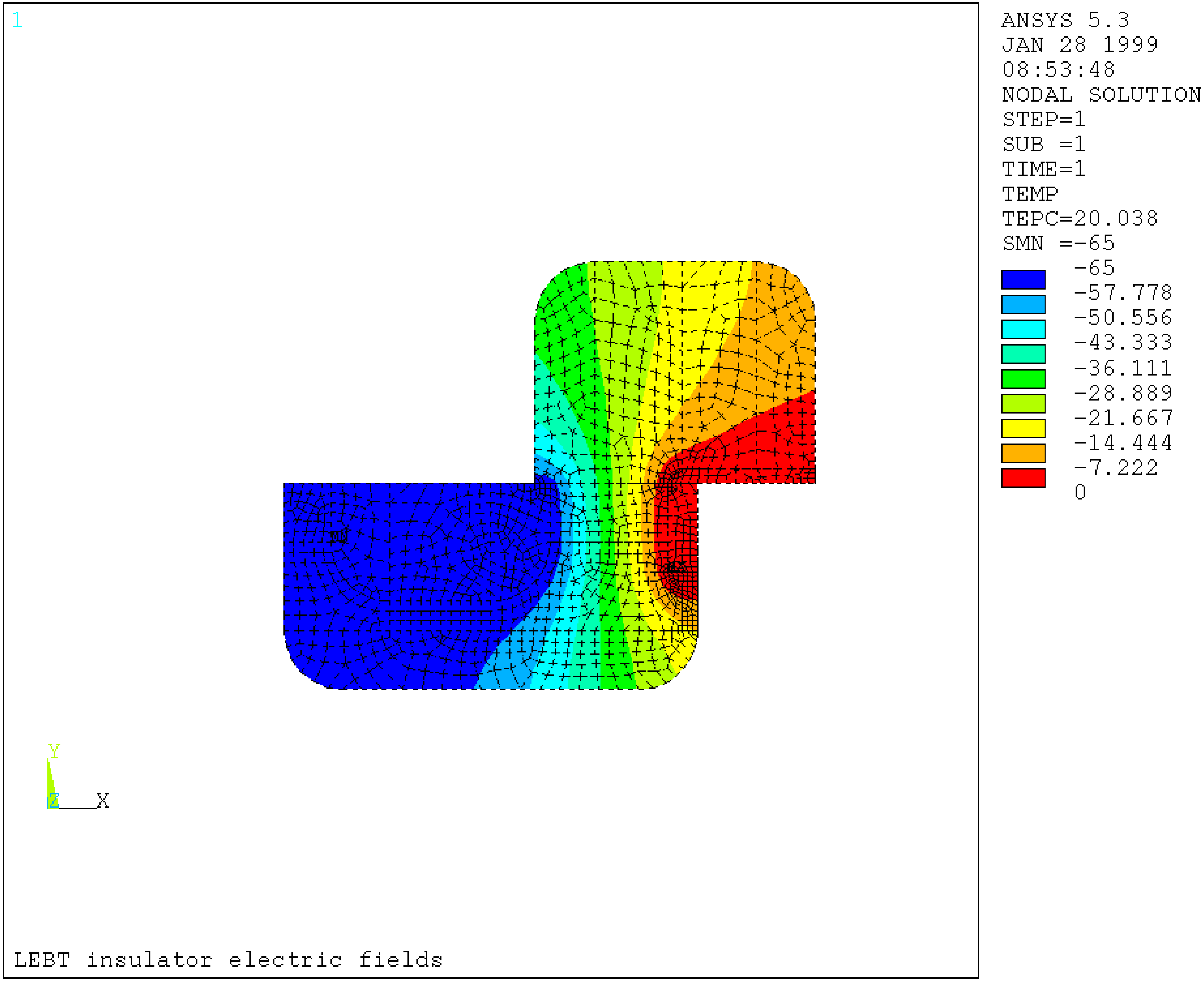
Y
Z
X
LEBT insulator electric fields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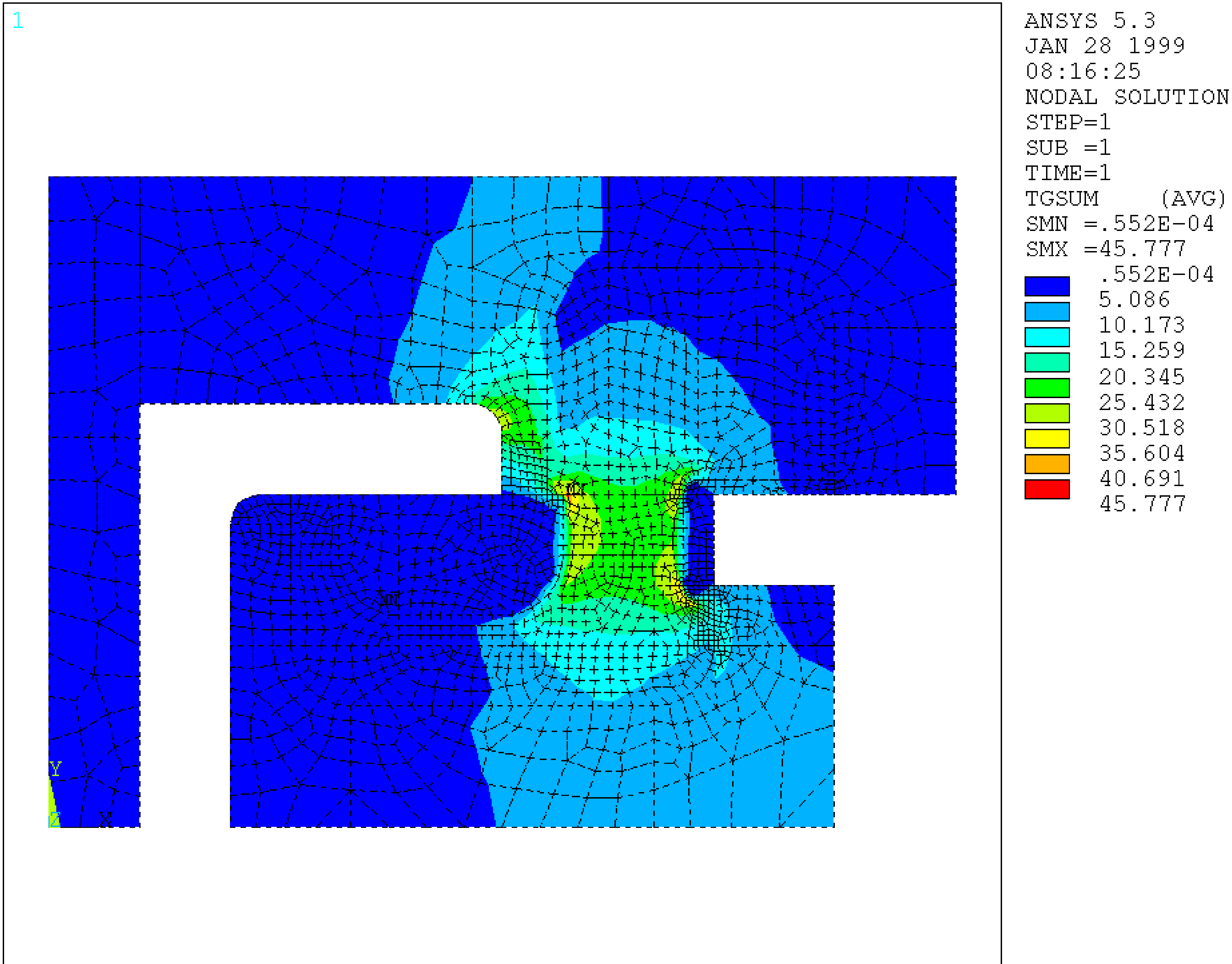
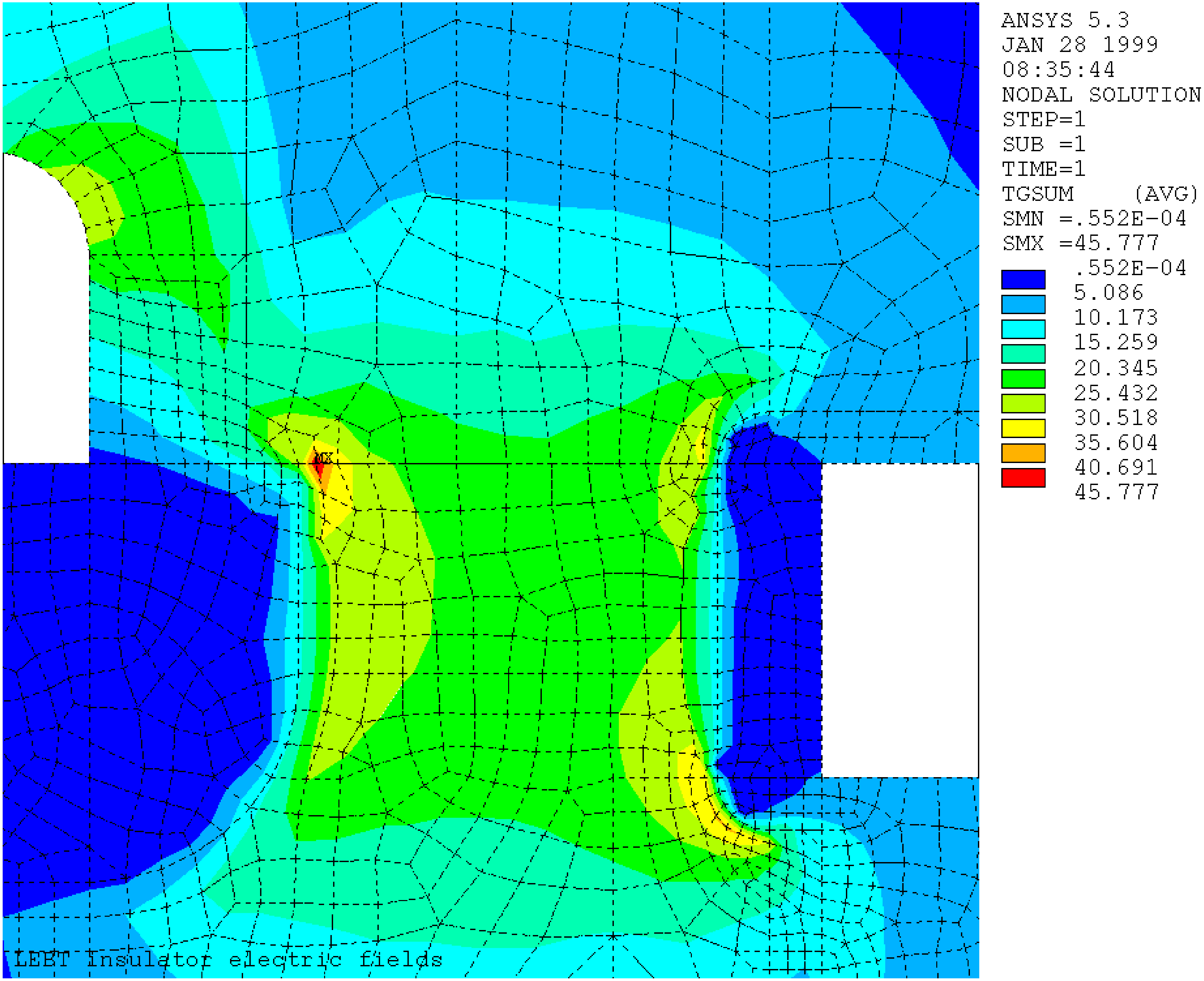
LEBT insulator electric fields



LEBT insulator electric fields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35.604
40.691
45.777
MX
LEBT insulator electric fields